Grayling 1 Information Base For Generation of Synthetic Thermal Scenes

Jerrell R. Ballard, Jr.

U.S. Army Engineer Waterways Experiment Station
Vicksburg, MS

SWOE Report 94-1
January 1994

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FOREWORD

SWOE Report 94-1, January 1994, was prepared by J.R. Ballard, Jr. of U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

This report is a contribution to the Smart Weapons Operability Enhancement (SWOE) Program. SWOE is a coordinated, Army, Navy, Marine Corps, Air Force and ARPA program initiated to enhance performance of future smart weapon systems through an integrated process of applying knowledge of the broadest possible range of battlefield conditions.

Performance of smart weapons can vary widely, depending on the environment in which the systems operate. Temporal and spatial dynamics significantly impact weapon performance. Testing of developmental weapon systems has been limited to a few selected combinations of targets and environmental conditions, primarily because of the high costs of full-scale field tests and limited access to the areas or events for which performance data are required.

Performance predictions are needed for a broad range of battlefield environmental conditions and targets. Meeting this need takes advantage of significant DoD investments by Army, Navy, Marine Corps and Air Force in 1) basic and applied environmental research, data collection, analysis, modeling and rendering capabilities, 2) extensive target measurement capabilities and geometry models, and 3) currently available computational capabilities. The SWOE program takes advantage of these DoD investments to produce an integrated process, the SWOE Process.

SWOE is developing, validating, and demonstrating the capability of the SWOE Process to handle complex target and environment interactions for a broad range of battlefield conditions. SWOE is providing the DoD smart weapons and autonomous target recognition (ATR) communities with a validated capability to integrate measurements, information bases, modeling, and simulation techniques for complex environments. This is a DoD-wide partnership that works in concert with advanced weapon system developers and major weapon system test and evaluation programs.

The SWOE program started in FY89 under Balanced Technology Initiative (BTI) sponsorship. Present sponsorship is by the U.S. Army Corps of Engineers (lead service), the individual services, and the Joint Test and Evaluation (JT&E) program of the Office of the Director of Test & Evaluation, Office of the Under Secretary of Defense OUSD(A/DT&E).

The Joint Test Director is Dr. J.P. Welsh. The Deputy Test Directors are: (Army) LTC Jerre Wilson and (Air Force) Maj Richard Jennings. The Integration Manager is Mr. Richard Palmer. The Modeling Configuration Manager is Dr. George G. Koenig.

SMART WEAPONS OPERABILITY ENHANCEMENT
USAF
ARMY NAVY
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SWOE

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13. ABSTRACT *(Maximum 200 words)*

Procedures are being developed for the environmental information base component of the Smart Weapons Operability Enhancement/Joint Test and Evaluation (SWOE/JT&E) Program analytical thermal infrared scene generation procedure. Scope is limited to documentation of the information base content and data processing/analysis procedures developed to satisfy other component requirements such as thermal signature modeling, thermal radiance field predictions, and generation of realistic graphic representations of the three-dimensional thermal backgrounds.

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Contents

Preface

The study reported herein was conducted during the period October 1992 to July 1993 by personnel of the Natural Resources Division (NRD), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES). The study was authorized by Dr. J. P. Welsh, Joint Test Director, Smart Weapons Operability Enhancement (SWOE) Joint Test and Evaluation Program (JT&E), Hanover, NH. LTC Jerre W. Wilson was the Army Deputy Director, SWOE JT&E.

WES has prepared three technical reports on Grayling 1 in support of the SWOE/JT&E Program. These are as follows:

a. "Grayling 1 Information Base for Generation of Synthetic Thermal Scenes"

b. "Grayling 1 Site Characterization and Data Summary"

c. "Analysis of Thermal Imagery Collected at Grayling 1, Grayling, Michigan"

Mr. Jerrell R. Ballard, Jr., Environmental Characterization Branch (ECB), NRD, was Principal Investigator and was responsible for design and development of the digital information base and data analysis procedures. Mr. R. Eddie Melton, Mr. Mark R. Graves, and Dr. M. Rose Kress, ECB, contributed to data analysis. Mr. Ballard prepared the report.

The work was conducted under the general supervision of Mr. Harold W. West, Chief, ECB; Dr. Robert M. Engler, Chief, NRD; and Dr. John Harrison, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	2.54	centimeters

1 Introduction

Background

The Smart Weapons Operability Enhancement/Joint Test and Evaluation (SWOE/JT&E) Program is a multiservice (U.S. Army, Navy, and Air Force) initiative aimed at providing the technology to simulate complex environmental backgrounds for use by smart weapons designers, developers, and testers. The smart weapons being designed to locate and acquire targets automatically must be able to isolate targets in relatively complex and varied environmental scenes. The technology provided by the SWOE/JT&E program will enhance the ability to characterize the effects of various terrain and atmospheric conditions on the smart weapons sensor performance.

Purpose and Scope

The purpose of this report is to document the methods used and developed for the information base component of the SWOE/JT&E thermal infrared scene generation procedure. This report is limited to the documentation of the information base content and procedures used to develop the Grayling 1 information base. The numerical models and other main components of the SWOE/JT&E thermal infrared scene generation procedure will be described in other reports.

Landscape Area

An area at Camp Grayling, MI, was selected for application of the environmental information base procedures. The area selected is illustrated in Figure 1. The landscape area considered for the information base is approximately 1.42 by 1.22 km with local relief of about 29 m. All geographic data were projected into the universal transverse Mercator (UTM)

projection in zone 16 and referenced to the North American Datum 1983 (NAD83). Detailed in the adjacent tabulation are the geographic coordinates of the Grayling 1 environmental information base extents.

Geographic Limits (UTM zone 16)		
North Edge	4952770.0	northings
South Edge	4951550.0	northings
East Edge	688100.0	eastings
West Edge	686680.0	eastings

2 Information Base Design and Content

Information Base Function

The function of the Grayling 1 information base in the SWOE/JT&E thermal infrared scene generation procedure is to provide all spatial and tabular data required by each component in the procedure. This requires providing descriptive environmental data on all combinations of terrain and atmospheric conditions within the designated geographical area.

The information base utilizes the concept of landscape units to describe the environmental conditions of the terrain. This landscape unit and its development is described in detail in Kress (1992). This report provided guidance on determining relevant environmental factors necessary for the Grayling 1 information base.

Information Base Content

The information base contains four kinds of digital data: terrain (e.g., topography, soil types, and vegetation types); meteorological data (e.g., air temperature, visibility, and soil moisture); three-dimensional (3-D) geometric tree models; and texture data. Digital data used in the SWOE scene generation procedure are stored in SWOE/JT&E specific formats described in Appendix A.

Digital terrain data are representations of the geographical area's surface stored in computer-compatible formats. These data depict characteristics such as elevation, vegetation types, soil types, slope, slope-aspect, and other relevant environmental information.

Meteorological data are required during the thermal infrared scene generation procedure and have influence on thermal model predictions (Balick, Link, and Scoggins 1981; Smith et al. 1981). Data collected from

from multiple sites (Hahn and Berry 1994) were averaged hourly and used as input to the scene generation procedure.

3-D vegetation geometric tree model data are representations of predominant 3-D features in the study area. The data are typically representations of large vegetation (trees and bushes) and vegetation structures (forest stands). The tree/forest stands were depicted using tree models and population density data collected at the Grayling 1 site. Included with the model data are tables indicating temporal state and changes of the geometric models resulting from winter effects.

The physics-based thermal signature prediction models (Hummel et al. 1991) used in the SWOE scene generation procedure require as inputs complete descriptions of the physical and thermal attributes of each landscape unit. These data are provided in tabular format for each landscape feature.

3 Information Base Development

As the first step in the development of the Grayling 1 information base, a list of factors required by each thermal prediction model pertaining to the environment was compiled. This process resulted in a list of environmental factors for generation of synthetic scenes. Specification of the factors and their data types defined the information base content and development specifications. Listed in Table 1 are the factors contained in the Yuma 1 information base.

Terrain Data

Six digital terrain data files are required in the SWOE scene generation procedure: topographic elevation, ground slope magnitude, slope aspect, vegetation type, and surface and subsurface soil type. These data files are described below.

Topographic elevation

Digital topographic elevation data define the basic 3-D geometry of the landscape and are used directly during generation of synthetic scenes. The initial digital elevation data for the Camp Grayling area were developed using a 4-m grid cell spacing. These data were generated using the Terrain Information Extraction System (TIES) by the U.S. Army Engineer Topographic Engineering Center (USACE-TEC) Fort Belvoir, VA, with 1:12,000 color aerial photo stereo pairs. The elevation data were imported into the Environmental Systems Research Institute (ESRI) ARC-INFO system and transformed into a triangular irregular network (TIN). The TIN data along with supplemental elevation data from the U.S. Army Engineer Waterways Experiment Station (WES) topographic field survey (Hahn and Berry 1994) were interpolated to produce a 1-m elevation grid array covering the 1.42- by 1.22-km area. The resulting 1-m elevation

grid array is illustrated using a 2-m contour interval in Plate 1. A 3-D wire frame perspective using the 1-m data is shown as Figure 2.

Ground slope magnitude and slope aspect

Ground slope magnitude is defined as the inclination of the earth's surface from horizontal. Slope aspect, the orientation of the surface normal, is referenced clockwise from true north. Slope and slope-aspect are used to determine the solar radiation incident to the earth's surface that affects thermal signature. Values for both are required in the synthetic scene generation procedure for each landscape unit.

Digital terrain data depicting slope and slope-aspect values were calculated using the generated 1-m topographic elevation data. A slope value in degrees and a slope-aspect value expressed as degrees from true north (ESRI ARC-INFO) were calculated for each 1- by 1-m grid cell within the elevation data array.

Numerical model sensitivity in the SWOE scene generation procedure made it necessary to reduce the spatial variability in the slope and slope-aspect digital terrain data by grouping values into a limited number of classes. For each grid cell, the digital slope and slope-aspect value was reassigned to an appropriate class. The class ranges are listed in Tables 2 and 3. Class midpoints are used during numerical calculations of surface temperatures and radiances. Plates 2 and 3 illustrate the distribution of slope and slope-aspect classed values, respectively, within the 1.42- by 1.22-km area.

Vegetation types

Thermal prediction models are available for nonvegetated areas (bare ground), short grass, medium-height grass vegetation, coniferous and deciduous forest canopy, and individual (isolated) trees. All vegetation within the landscape area were assigned one of these five classes.

A vegetation type map, compatible with capabilities of the current numerical models, was prepared by USACE-TEC for the Camp Grayling area using 1:12,000 color aerial photography. These data were field checked, and 1-m vegetation grid data were generated by WES. Plate 4 illustrates the vegetation type distribution and includes a no-vegetation (bare ground) category. Table 4 shows the types and descriptions of vegetation.

Surface and subsurface soil types

Unified Soil Classification System (USCS) soil types for the Camp Grayling area were acquired from existing reports (Hickok and Associates 1987). Because of small variability in the soil types and model sensitivity,

both surface soil and subsurface soil were classed as sand (SP by USCS). Data on surface soil and subsurface soil characteristics were compiled and are listed in Appendix B.

Composite Terrain Data Layer

The digital terrain data were then used to identify and delineate uniform landscape units. Landscape units are contiguous areas with uniform conditions of the surface soil type, subsurface soil type, vegetation type, ground slope, and slope aspect.

A new digital terrain data file was generated that combined the values of the five existing data files by simply assigning a code to each unique combination of existing values that actually occurred. This data file represents a combination of vegetation type, surface soil type, subsurface soil type, ground slope, and slope aspect. Executed in the Geographic Resources Analysis System (GRASS-GIS), this step resulted in a raster file that was geographically coregistered to the other raster digital terrain files. This processing operation resulted in 100 unique combinations of the five terrain factors. Plate 5 shows these combinations and illustrates the complexity of the Grayling database. Table 5 lists the 100 unique combinations that occurred in the Camp Grayling landscape area, their description, and the landscape unit code assigned to each combination.

Terrain Parameters

In addition to the digital terrain data, a wide range of quantitative data defining the physical, thermal, and spectral attributes of each landscape unit are required for the SWOE scene generation procedure. These parameters are listed in Table 1. Complete descriptions of these attributes, as well as estimates of their value for various vegetation and soil types, can be found in Balick, Link, and Scoggins (1981); Smith et al. (1981); Dornbusch (1990); Hummel et al. (1991); Jones (1991); and Jordan (1991).

Meteorological Data

Also required in the scene generation procedure are meteorological data, including data on surface weather, atmospheric conditions, and solar loading. Meteorological parameters used in the procedure are listed in Table 1.

Six weeks of meteorological data were collected using several field stations during the SWOE/JT&E field program at Camp Grayling during the period 9 Septemper 1992 to 15 October 1992; hourly data were summarized for the Site E area and are stored in the information base. These data represent the summer-to-fall transition weather conditions for the months of September and October 1993 (Hahn and Berry 1994).

3-D Geometric Tree Data

Three-dimensional geometric model data are representations of predominant 3-D vegetative features in the study area such as trees and forest stands. There were no urban features within the area. Data to support these representations include geographic tree location, height, species, stem and branching structures, foliage sizes, and densities.

There are three major tree types at the Camp Grayling study area. In their general order of predominance, the tree types (species) are black oak (*Quercus velutina*), jack pine (*Pinus banksiani*), and aspen (*Populus tremuloides*). The oak-type forests occurred throughout the study area and were composed of large trees with heights of 50 to 75 ft. The pine forests within the study area were frequently mixed with oaks. The jack pine stands were typically 5 to 10 in. in diameter (diameter at breast height) and reached heights of 50 to 80 ft. The aspen-type forests, although common within the Camp Grayling reservation, were not present in the SWOE test area (see Figure 1) (Hickok and Associates 1987).

To obtain data of vegetative stem and branching structures and foliage characteristics, six jack pine trees, six black oak trees, and two aspens were characterized by surveying the geometry of the stems and branches. Measurements for an approximately 50-year-old black oak tree (inside a deciduous forest) are shown in Table 6. By generalizing these measurements for same species of similar ages, 3-D geometric tree models were developed to describe five different tree shapes for the two dominant species. The models and their descriptions are included in Table 7. These models were described and developed using Lindenmayer systems. The Lindenmayer system, termed L-system, is a string rewriting mechanism used commonly in describing the branching topology of the modeled plants. (Prusinkiewicz and Hanan 1989). An L-system description of the black oak forest tree is shown in Table 8. Using the L-system descriptions, 3-D cylinder descriptions are produced for computer graphic rendering. A 3-D cylinder listing for the black oak forest tree is presented in Table 9, and a 3-D stick and leaf plot is provided in Figure 3.

To obtain geometric locations of individual trees, basal locations of 70 trees and bushes were surveyed in the vicinity of Site E using techniques described in Hahn and Berry (1994). Forest densities were calculated using standard forestry density measurements. Figures 4-6 show the locations of trees for two pine stands and one oak forest stand, respectively.

Using the forest density calculations, basal locations were generated and combined with surveyed locations to arrive at a total of 4,683 basal locations within the 1.42- by 1.22-km SWOE Grayling 1 study area. Forest edges along the "valley area" of the site were mapped in more detail by digitizing tree locations, size, and types using aerial photography and ground truth data.

A model scale value was assigned to each tree location by dividing the measured tree height by the height of its corresponding geometric model. This scale value would be applied to the geometric model at the time of rendering. This technique allows scaling a representative geometric model to the exact height of each measured tree. For each location, the tree basal elevation, tree model, and model scale were assigned. An example of the tree location file is in Table 10.

Foliage characteristics were acquired by measuring leaf cluster lengths and average leaf lengths and widths (Table 11). Also acquired were data for the physical parameters for the thermal models (Tables 12 and 13). These data were used for leaf density calculations and thermal predictions.

For verification of model scale and tree basal positions, several 3-D color graphical plots of the SWOE database were generated. These are shown in Plates 6-9.

Texture Data

Texture data were developed for the scene generation procedure that corresponded to a single vegetation type at a specific time of day. Forty-five separate synthetic texture images were generated based on existing thermal imagery. Each texture image file corresponded to a single background terrain type at a specific time of day. The texture data were used by the SWOE rendering software system for application of thermal texture to terrain areas for which a single mean temperature was estimated.

Texture data were developed from Remote Minefield Detection System (REMIDS) imagery of terrain cover types analogous to those found at the Grayling 1 study area. Imagery segments of selected terrain cover types were then processed to compute a finite impulse response (FIR) kernel (Cadzow et al. 1992). Three replicate synthetic textures, each 256 × 256 pixels, were created with each FIR kernel by using different random number seeds for the white noise generator. Each histogram of each synthetic texture image then transformed to a Gaussian distribution with a mean of 128 and a standard deviation of 32. Table 14 lists the texture image files generated for the Grayling 1 information base. Each of these texture image files will be correctly scaled to correspond to the gray level to temperature scaling in the rendering process. This is accomplished by subtracting 128 digital gray levels from all values in the texture image file to shift the mean to zero, then the spread of the gray levels in texture image

must be expanded or compressed to correspond to the thermal standard deviation of the appropriate terrain cover type and final scene thermal scaling. Thermal standard deviations are listed in Table 15.[1]

WES is currently developing a physics-based procedure (Weiss et al., in preparation) for determining texture data; this procedure will be used to generate additional texture data for the Grayling site.

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1 External Memorandum, 14 December 1992, Bruce Sabol, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

4 Summary

This report documents the methods developed for the environmental information base component of the SWOE/JT&E thermal infrared scene generation procedure. An environmental information base was designed and developed for a 1.42- by 1.22-km site at Camp Grayling, MI.

Considerable effort was devoted to verifying geometric locations of individual tree basal locations and their appropriate 3-D geometric models. An L-system description of these models allowed for a realistic rendering of the vegetation without the need for highly detailed measurements.

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Weiss, R. A., Sabol, B. M., Smith, J. A., and Bales, J. W. "Physics-based IR terrain radiance texture model," Technical Report in preparation, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

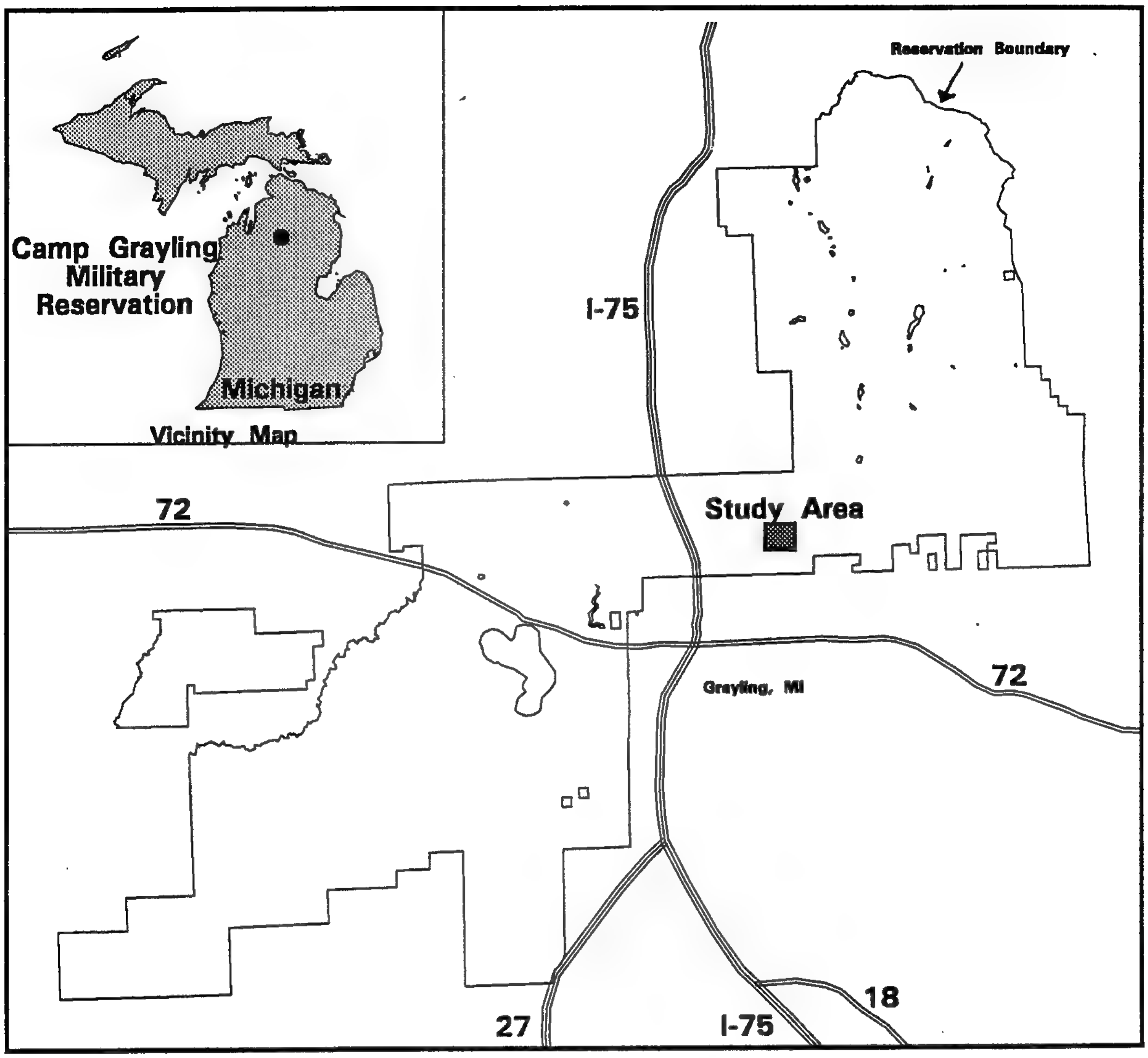


Figure 1. Grayling 1 Environmental Information Base location map

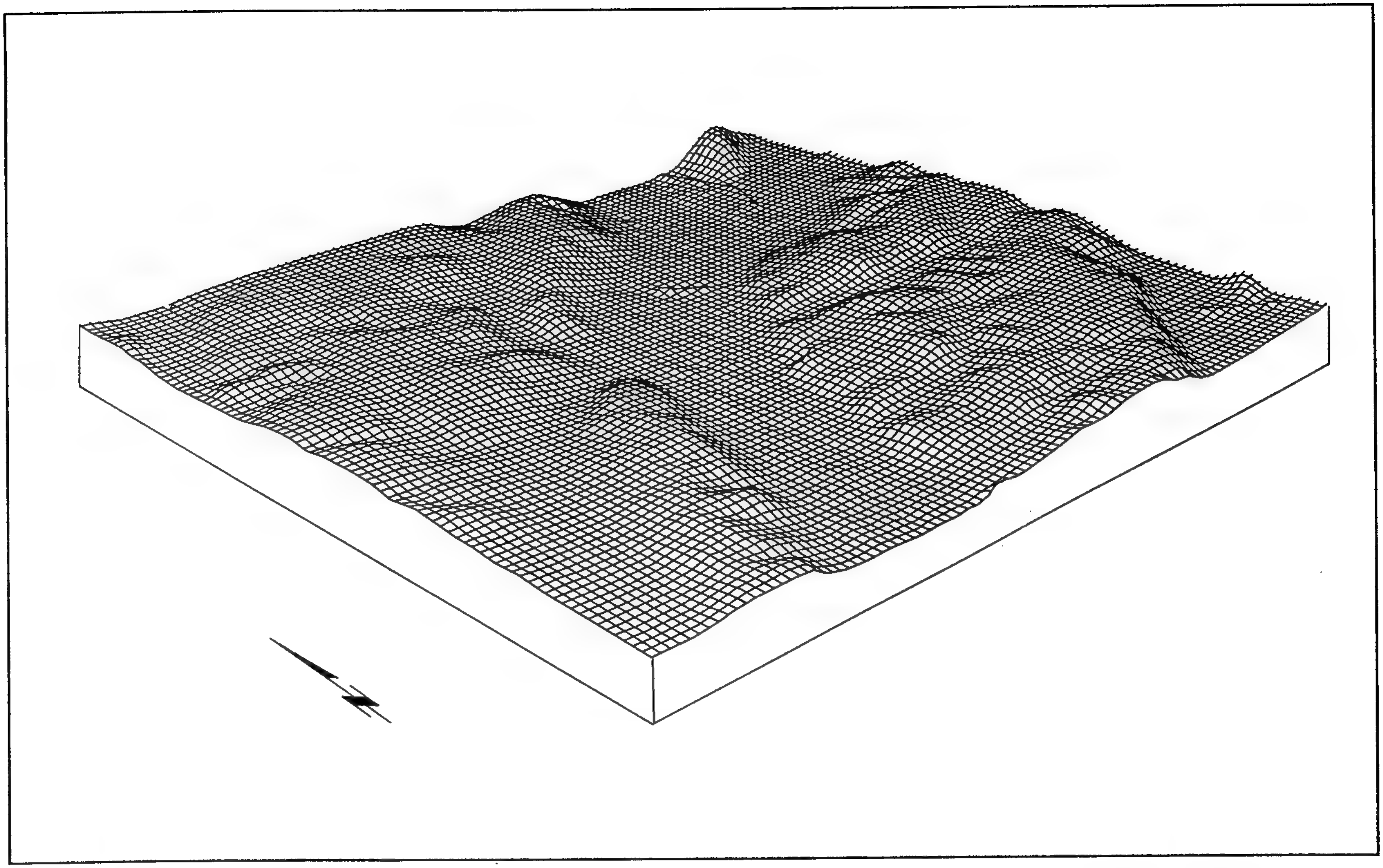


Figure 2. Three-dimensional view of the Grayling 1 Environmental Information Base elevation component. Vertical relief is doubled for graphic depiction

Figure 3. Stick-and-leaf plot of the black oak geometric model (forest_oak.wes) used in the forest stand. The model height is 9 m

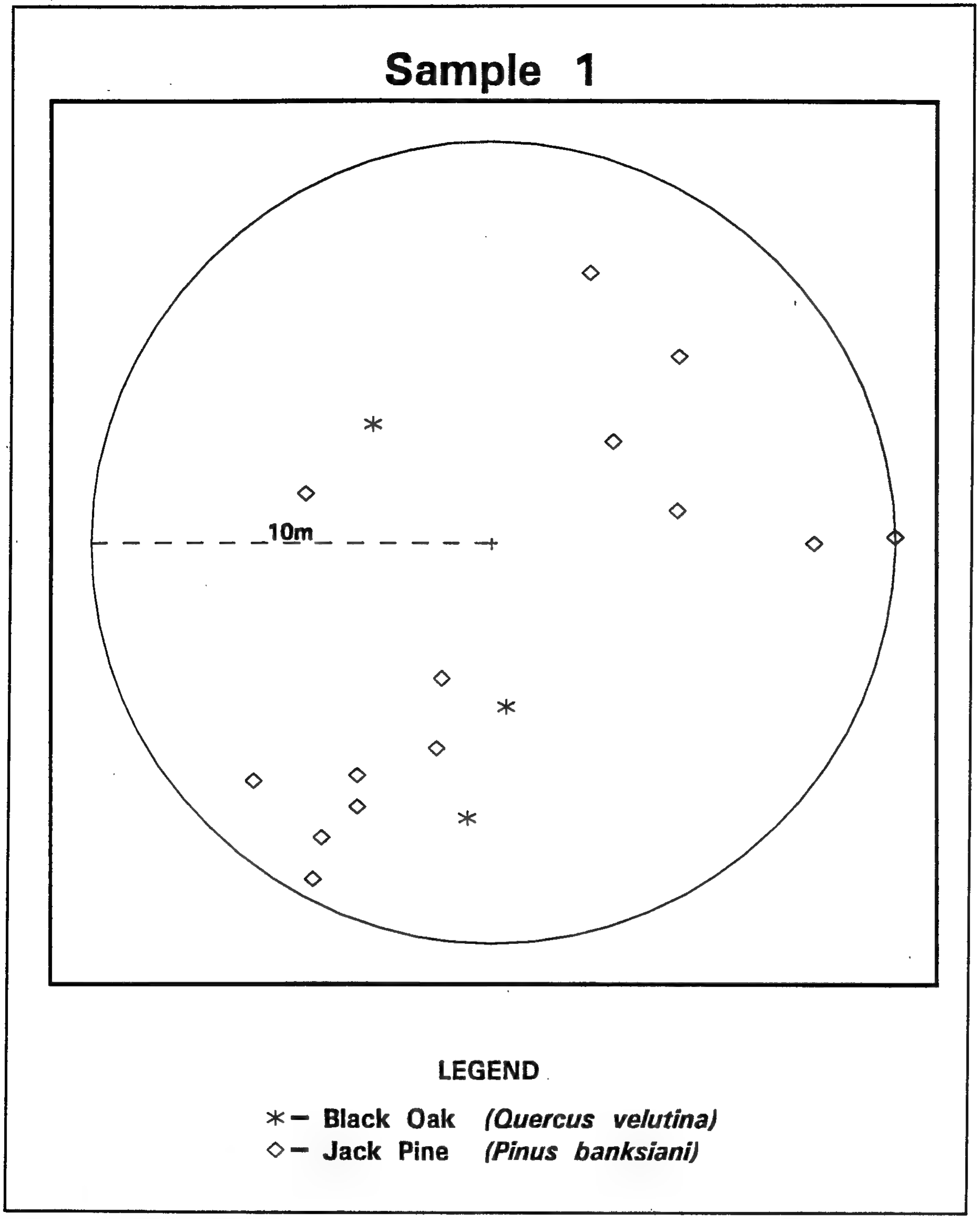


Figure 4. Forest stand density measurement for west side of forest stand near Site E

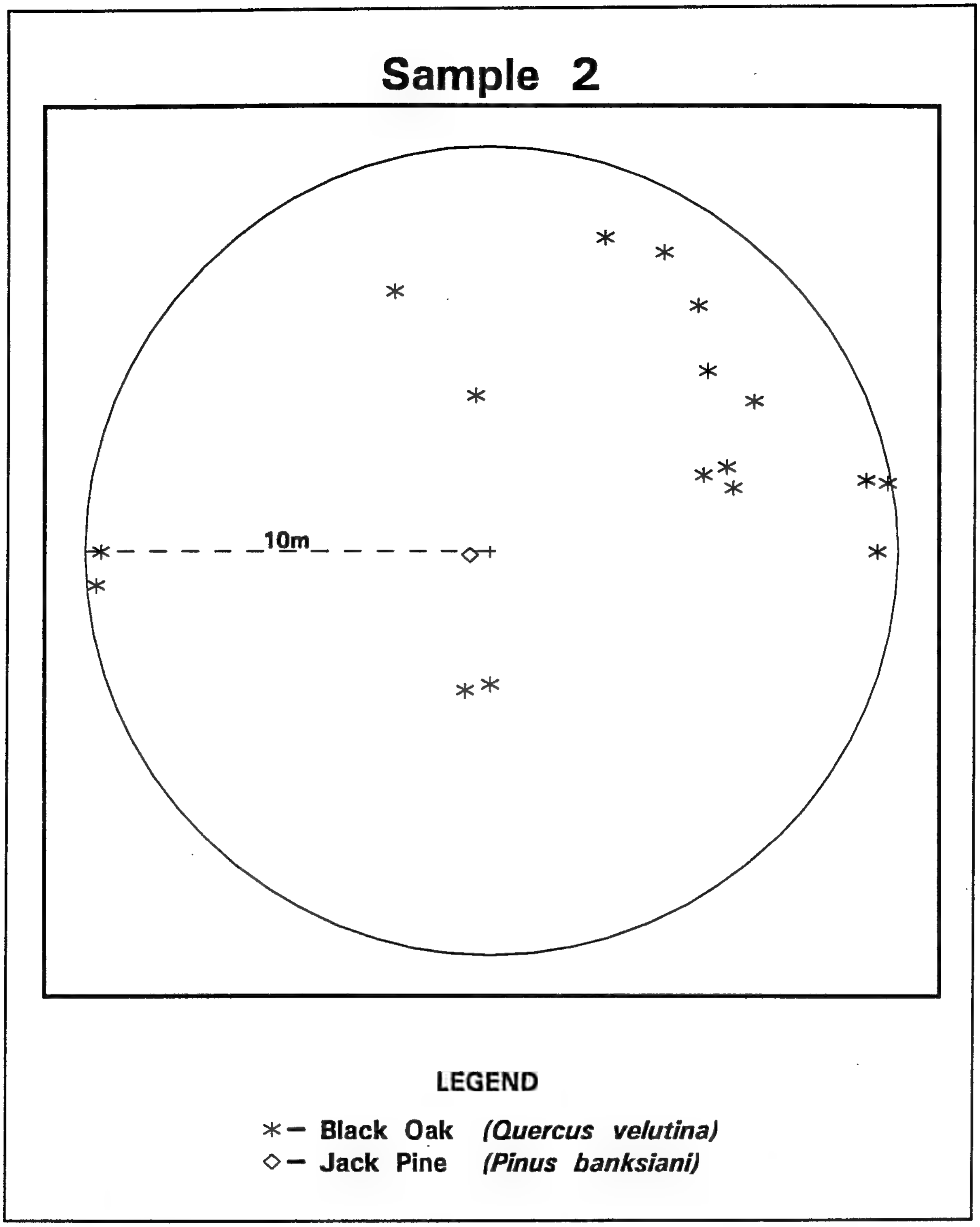


Figure 5. Forest stand density measurement for east side of forest stand near Site E

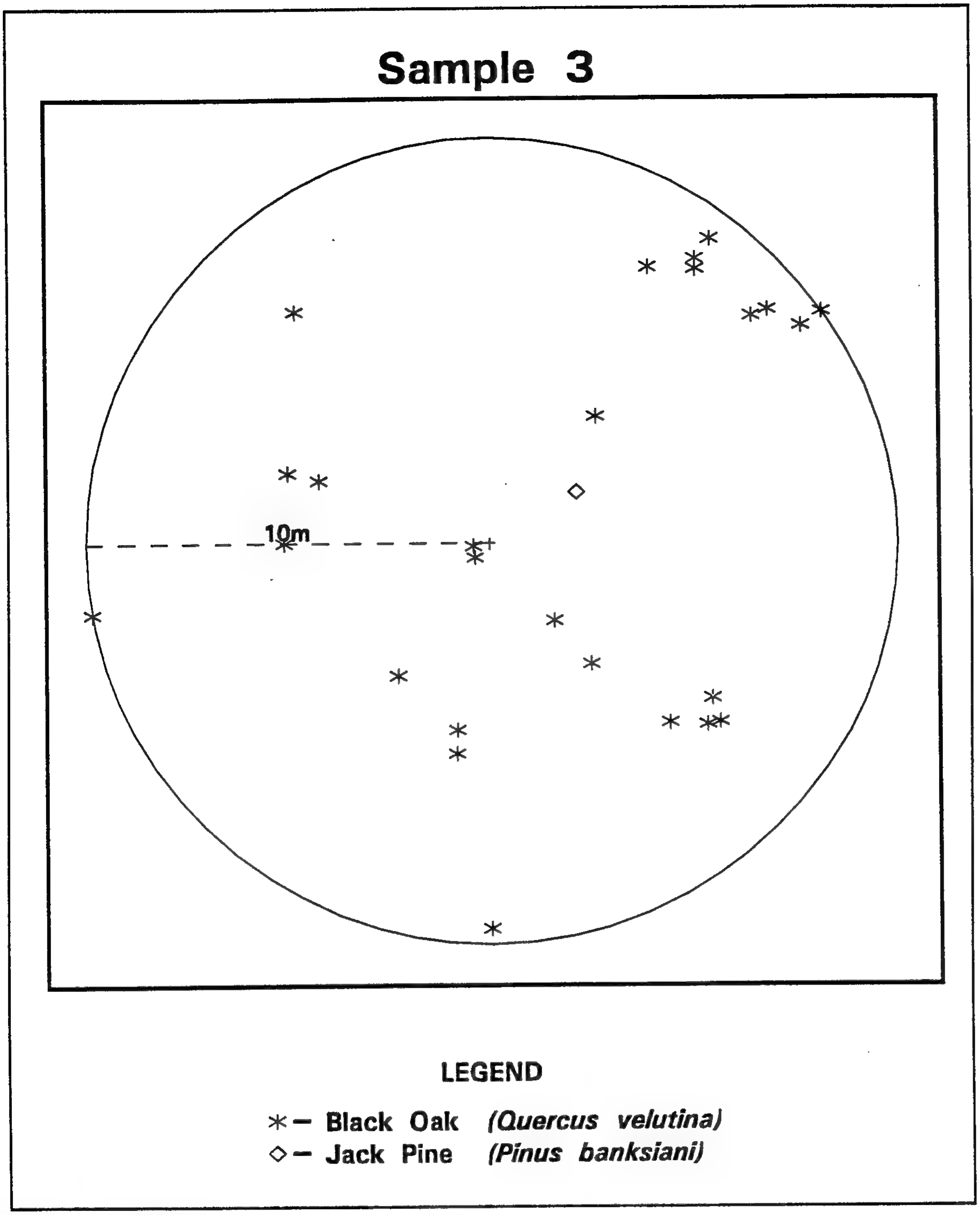


Figure 6. Forest stand density measurement for Site F

Table 1
Grayling 1 Information Base Content

Topographic elevation
Ground slope magnitude
Slope aspect

<u>Vegetation type</u>
Grass
- Percent ground cover
- Height
- State - measure of plant vigor
- Longwave emissivity
- Shortwave absorptivity

Forest canopy
- Stomatal resistance
- Longwave emissivity
- Shortwave absorptivity
- Longwave transfer coefficient
- View angle matrix

<u>Surface and subsurface soil type</u>
Number of nodes in layer
Quartz content of soil
Roughness length
Bulk transfer coefficient for eddy diffusivity
Turbulent Ptandtl number
Turbulent Schmidt number
Windless convection coefficient
Shortwave absorptivity
Intrinsic density of dry material
Bulk density of dry material
Heat capacity of dry mineral solids
Dry soil thermal conductivity
Soil coarseness code
Plasticity index
Albedo
Hemispherical emissivity
Thermal diffusivity
Temperature of nodes
Thickness of nodes
Total bulk water density

<u>Meteorological</u>
Latitude of recording station
Longitude of recording station
ZULU time difference
Elevation of recording station
Height above ground of recording station
Averaged surface albedo of landscape area
Time interval of data
Year
Julian day
Local hour, time
Atmospheric pressure
Air temperature
Relative humidity
Wind speed
Wind direction
Visibility
Global incoming solar radiation
Direct incoming solar radiation
Diffuse incoming solar radiation
Downwelling thermal infrared radiation
Low cloud cover, percent
Low cloud cover, type
Midlevel cloud cover, percent
Midlevel cloud cover, type
High cloud cover, percent
High cloud cover, type
Precipitation type
Precipitation rate
Precipitation grain size

Table 2 Class Ranges for Terrain Slope		
Class	Class Range, deg	Slope Value Used for Calculation
1	0-5	3.0
2	>5-10	8.0
3	>10-15	13.0
4	>15-20	18.0
5	>20	23.0

Table 3 Class Ranges for Slope-Aspect		
Class	Class Range, deg	Aspect Values Used for Calculation
1	1-90	45
2	91-180	135
3	181-270	225
4	271-360	315

Table 4 Vegetation Class Types	
Vegetation Type	Description
BARE	Bare ground, exposed surface soil
MVEG	Grass vegetation, medium density
DECI	Deciduous forest
CONF	Coniferous forest
MIXF	Mixed (deciduous, coniferous) forest

Table 5
Landscape Unit Codes and Descriptions Present in Camp Grayling, MI, Area

Landscape Feature Code	Vegetation Type	Surface Soil	Subsurface Soil	Ground Slope Value	Slope Aspect Value
001	BARE	SAND	SAND	03	045
002	BARE	SAND	SAND	03	135
003	BARE	SAND	SAND	03	225
004	BARE	SAND	SAND	03	315
005	BARE	SAND	SAND	08	045
006	BARE	SAND	SAND	08	135
007	BARE	SAND	SAND	08	225
008	BARE	SAND	SAND	08	315
009	BARE	SAND	SAND	13	045
010	BARE	SAND	SAND	13	135
011	BARE	SAND	SAND	13	225
012	BARE	SAND	SAND	13	315
013	BARE	SAND	SAND	18	045
014	BARE	SAND	SAND	18	135
015	BARE	SAND	SAND	18	225
016	BARE	SAND	SAND	18	315
017	BARE	SAND	SAND	23	045
018	BARE	SAND	SAND	23	135
019	BARE	SAND	SAND	23	225
020	BARE	SAND	SAND	23	315
021	MVEG	SAND	SAND	03	045
022	MVEG	SAND	SAND	03	135
023	MVEG	SAND	SAND	03	225
024	MVEG	SAND	SAND	03	315
025	MVEG	SAND	SAND	08	045
026	MVEG	SAND	SAND	08	135
027	MVEG	SAND	SAND	08	225
028	MVEG	SAND	SAND	08	315
029	MVEG	SAND	SAND	13	045
030	MVEG	SAND	SAND	13	135
031	MVEG	SAND	SAND	13	225
032	MVEG	SAND	SAND	13	315
033	MVEG	SAND	SAND	18	045
034	MVEG	SAND	SAND	18	135
035	MVEG	SAND	SAND	18	225
036	MVEG	SAND	SAND	18	315
037	MVEG	SAND	SAND	23	045
038	MVEG	SAND	SAND	23	135
039	MVEG	SAND	SAND	23	225
040	MVEG	SAND	SAND	23	315
041	DECI	SAND	SAND	03	045
042	DECI	SAND	SAND	03	135
043	DECI	SAND	SAND	03	225
044	DECI	SAND	SAND	03	315
045	DECI	SAND	SAND	08	045
046	DECI	SAND	SAND	08	135
047	DECI	SAND	SAND	08	225
048	DECI	SAND	SAND	08	315
049	DECI	SAND	SAND	13	045
050	DECI	SAND	SAND	13	135

(Continued)

Table 5 (Concluded)

Landscape Feature Code	Vegetation Type	Surface Soil	Subsurface Soil	Ground Slope Value	Slope Aspect Value
051	DECI	SAND	SAND	13	225
052	DECI	SAND	SAND	13	315
053	DECI	SAND	SAND	18	045
054	DECI	SAND	SAND	18	135
055	DECI	SAND	SAND	18	225
056	DECI	SAND	SAND	18	315
057	DECI	SAND	SAND	23	045
058	DECI	SAND	SAND	23	135
059	DECI	SAND	SAND	23	225
060	DECI	SAND	SAND	23	315
061	CONF	SAND	SAND	03	045
062	CONF	SAND	SAND	03	135
063	CONF	SAND	SAND	03	225
064	CONF	SAND	SAND	03	315
065	CONF	SAND	SAND	08	045
066	CONF	SAND	SAND	08	135
067	CONF	SAND	SAND	08	225
068	CONF	SAND	SAND	08	315
069	CONF	SAND	SAND	13	045
070	CONF	SAND	SAND	13	135
071	CONF	SAND	SAND	13	225
072	CONF	SAND	SAND	13	315
073	CONF	SAND	SAND	18	045
074	CONF	SAND	SAND	18	135
075	CONF	SAND	SAND	18	225
076	CONF	SAND	SAND	18	315
077	CONF	SAND	SAND	23	045
078	CONF	SAND	SAND	23	135
079	CONF	SAND	SAND	23	225
080	CONF	SAND	SAND	23	315
081	MIXF	SAND	SAND	03	045
082	MIXF	SAND	SAND	03	135
083	MIXF	SAND	SAND	03	225
084	MIXF	SAND	SAND	03	315
085	MIXF	SAND	SAND	08	045
086	MIXF	SAND	SAND	08	135
087	MIXF	SAND	SAND	08	225
088	MIXF	SAND	SAND	08	315
089	MIXF	SAND	SAND	13	045
090	MIXF	SAND	SAND	13	135
091	MIXF	SAND	SAND	13	225
092	MIXF	SAND	SAND	13	315
093	MIXF	SAND	SAND	18	045
094	MIXF	SAND	SAND	18	135
095	MIXF	SAND	SAND	18	225
096	MIXF	SAND	SAND	18	315
097	MIXF	SAND	SAND	23	045
098	MIXF	SAND	SAND	23	135
099	MIXF	SAND	SAND	23	225
100	MIXF	SAND	SAND	23	315

Table 6
Measurements for a Black Oak Tree

Sample Number	Branch Height, cm	Branch Diameter, cm	Branch Angle	Branch Length,cm	Trunk Diameter, cm
001	145	3.0	50	150	15.5
002	200	2.5	50	150	16.5
003	245	2.5	45	160	15.0
004	275	3.0	40	180	13.5
005	300	3.5	40	230	14.0
006	330	2.0	50	100	14.0
007	360	1.9	45	120	13.0
008	385	4.5	50	340	14.0
009	441	5.0	50	230	13.5
010	485	3.5	40	240	13.0
011	555	4.0	60	270	12.0
012	560	3.0	50	210	12.0
013	675	3.0	40	230	10.0
014	682	3.5	90	170	9.5
015	722	3.0	45	180	10.0
016	760	2.5	45	140	8.5
017	865	2.5	40	140	4.5
018	913	2.5	45	160	4.5

Note: Site number—G072; date—9/11/92; local description—deciduous forest; base circumference—60 cm; species—Black Oak.

Table 7
Three-Dimensional Tree Models

Filename	Description
forest_oak.wes	Black Oak tree forest model (9-m height)
forest_pine.wes	Jack Pine tree forest model (15.7-m height)
valley_oak1.wes	Black Oak tree valley model #1 (3.3-m height)
valley_oak2.wes	Black Oak tree valley model #2 (1.4-m height)
valley_pine.wes	Jack Pine tree valley model (4.6-m height)

Table 8
L-System Description of Black Oak Forest Tree

```
/*****************************************************************/
/* Description: This code generates a forest oak tree in the lsys   */
/*              programing language. The tree is modeled after      */
/*              the oak trees found in the forests of Grayling, MI. */
/* Date:        September 24, 1992                                  */
/*****************************************************************/

#define maxgen 19

START: !(19.47) F(244) A(244) C(2.5,2)

p1: A(ht)     ->(.1666) [B(ht)]!(19.47-.0158*ht) &(1) F(34)/(113)A(ht+34)
              ->(.1666) [B(ht)]!(19.47-.0158*ht) &(1) F(34)/(156)A(ht+34)
              ->(.1670) [B(ht)]!(19.47-.0158*ht) &(0) F(34)/(113)A(ht+34)
              ->(.1666) [B(ht)]!(19.47-.0158*ht) &(0) F(34)/(156)A(ht+34)
              ->(.1666) [B(ht)]!(19.47-.0158*ht) &(-1) F(34)/(113)A(ht+34)
              ->(.1666) [B(ht)]!(19.47-.0158*ht) &(-1) F(34)/(156)A(ht+34)

p2: B(ht)     -> &(49.17+.0078*ht)!(4.49939-.0015*ht) \
                 C(248.65817 + 0.03003 * ht,4.49939-.0015*ht)

p3: C(len,w)  ->(.25) F(len*.25) [+(45) S(len*.75,w)] &(15) +(5)F(len*.25) \
                                 [ -(45) D(len*.50,w)] &(-15) F(len*.25) \
                                 [ +(30) D(len*.25,w)] &(15) F(len*.25) M
              ->(.25) F(len*.25) [-(45) S(len*.75,w)] &(15) -(5)F(len*.25) \
                                 [ +(45) D(len*.50,w)] &(-15) F(len*.25) \
                                 [ -(30) D(len*.25,w)] &(15) F(len*.25) M
              ->(.25) F(len*.25) [+(45) S(len*.75,w)] &(20) +(10)F(len*.25) \
                                 [ -(45) D(len*.50,w)] &(-20) F(len*.25) \
                                 [ +(30) D(len*.25,w)] &(-20) F(len*.25) M
              ->(.25) F(len*.25) [-(45) S(len*.75,w)] &(-20) -(10)F(len*.25) \
                                 [ +(45) D(len*.50,w)] &(20) F(len*.25) \
                                 [ -(30) D(len*.25,w)] &(20) F(len*.25) M

p4: S(len,w)  -> !(w*.5) F(len*.5) [ +(45) D(len*.5,w)] &(20) F(len*.5) M

p5: D(len,w)  -> !(w*.5) F(len) M

p6: M         -> [f(11) E] [+(80) f(11) E] [-(80) f(11) E]

p7: E         -> f(5) &(65) [ f(4) J] /(78) \
                 f(5) &(65) [ f(4) J] /(78) \
                 f(5) &(65) [ f(4) J] /(78) \
                 f(5) &(65) [ f(4) J] /(78) \
                 f(5) &(65) [ f(4) J] /(78) \
                 f(5) &(65) [ f(4) J] /(78) \
                 f(5) &(65) [ f(4) J] /(78) \
                 f(5) &(65) [ f(4) J] /(78) \
                 f(5) &(65) [ f(4) J]

p8: J         -> { +(30) f(7) -(120) f(6)} { +(90) f(6) +(90) f(6) } \
                 { +(90) f(6) +(90) f(6) }
```

Table 9
3-D Cylinder Listing for Black Oak Forest Tree

GRAYLING I - SWOE/JT&E - Black Oak forest tree - Data sheets: G071, G072

Node	X1	Y1	Z1	Dia.	Node	X2	Y2	Z2	Dia.	
001	0.0	0.0	0.0	19.5	002	0.0	0.0	244.0	15.6	15.6
002	0.0	0.0	244.0	15.6	003	0.0	-49.8	284.2	4.1	4.1
002	0.0	0.0	244.0	15.6	012	0.0	0.6	278.0	15.1	15.1
003	0.0	-49.8	284.2	4.1	004	-67.9	-102.6	326.9	2.1	2.1
003	0.0	-49.8	284.2	4.1	007	-11.1	-109.4	304.7	4.1	4.1
004	-67.9	-102.6	326.9	2.1	005	-163.9	-102.6	326.9	2.1	2.1
004	-67.9	-102.6	326.9	2.1	006	-131.7	-172.8	341.4	2.1	2.1
007	-11.1	-109.4	304.7	4.1	008	62.3	-208.6	338.7	2.1	2.1
007	-11.1	-109.4	304.7	4.1	009	-21.6	-158.3	344.6	4.1	4.1
009	-21.6	-158.3	344.6	4.1	010	-62.1	-195.4	377.3	2.1	2.1
009	-21.6	-158.3	344.6	4.1	011	-30.1	-190.6	399.1	4.1	4.1
012	0.0	0.6	278.0	15.1	013	-46.2	20.9	317.8	4.1	4.1
012	0.0	0.6	278.0	15.1	022	0.5	1.0	312.0	14.5	14.5
013	-46.2	20.9	317.8	4.1	014	-121.8	-20.3	361.1	2.0	2.0
013	-46.2	20.9	317.8	4.1	017	-102.3	39.1	343.2	4.1	4.1
014	-121.8	-20.3	361.1	2.0	015	-191.1	10.2	420.8	2.0	2.0
014	-121.8	-20.3	361.1	2.0	016	-211.8	-51.4	375.9	2.0	2.0
017	-102.3	39.1	343.2	4.1	018	-153.1	151.0	380.7	2.0	2.0
017	-102.3	39.1	343.2	4.1	019	-150.4	54.3	382.9	4.1	4.1
019	-150.4	54.3	382.9	4.1	020	-202.2	37.0	416.8	2.0	2.0
019	-150.4	54.3	382.9	4.1	021	-206.6	72.5	408.3	4.1	4.1
022	0.5	1.0	312.0	14.5	023	37.6	36.5	351.1	4.0	4.0
022	0.5	1.0	312.0	14.5	032	1.1	1.3	346.0	14.0	14.0
023	37.6	36.5	351.1	4.0	024	124.3	25.0	392.3	2.0	2.0
023	37.6	36.5	351.1	4.0	027	84.3	73.7	375.5	4.0	4.0
024	124.3	25.0	392.3	2.0	025	191.5	-44.7	392.0	2.0	2.0
024	124.3	25.0	392.3	2.0	026	220.2	28.1	404.7	2.0	2.0
027	84.3	73.7	375.5	4.0	028	92.6	196.7	413.3	2.0	2.0
027	84.3	73.7	375.5	4.0	029	124.9	105.2	414.5	4.0	4.0
029	124.9	105.2	414.5	4.0	030	180.5	107.5	447.0	2.0	2.0
029	124.9	105.2	414.5	4.0	031	171.6	142.3	438.8	4.0	4.0
032	1.1	1.3	346.0	14.0	033	-17.3	-45.5	386.8	4.0	4.0
032	1.1	1.3	346.0	14.0	042	1.6	1.7	380.0	13.5	13.5
033	-17.3	-45.5	386.8	4.0	034	26.8	-120.9	429.3	2.0	2.0
033	-17.3	-45.5	386.8	4.0	037	-18.7	-80.3	441.3	4.0	4.0
034	26.8	-120.9	429.3	2.0	035	-0.9	-191.1	490.5	2.0	2.0
034	26.8	-120.9	429.3	2.0	036	60.1	-211.0	443.4	2.0	2.0
037	-18.7	-80.3	441.3	4.0	038	-107.1	-103.5	533.1	2.0	2.0
037	-18.7	-80.3	441.3	4.0	039	-27.1	-130.7	481.2	4.0	4.0
039	-27.1	-130.7	481.2	4.0	040	-3.9	-183.5	510.6	2.0	2.0
039	-27.1	-130.7	481.2	4.0	041	-41.7	-190.4	501.6	4.0	4.0
042	1.6	1.7	380.0	13.5	043	-34.0	38.4	420.1	3.9	3.9
042	1.6	1.7	380.0	13.5	052	1.8	2.5	414.0	12.9	12.9
043	-34.0	38.4	420.1	3.9	044	-23.1	126.1	461.3	2.0	2.0
043	-34.0	38.4	420.1	3.9	047	-68.8	89.7	439.7	3.9	3.9
044	-23.1	126.1	461.3	2.0	045	45.9	195.0	459.5	2.0	2.0
044	-23.1	126.1	461.3	2.0	046	-27.7	222.7	473.8	2.0	2.0
047	-68.8	89.7	439.7	3.9	048	-192.7	109.0	474.2	2.0	2.0
047	-68.8	89.7	439.7	3.9	049	-96.3	133.3	479.3	3.9	3.9
049	-96.3	133.3	479.3	3.9	050	-93.7	189.9	511.3	2.0	2.0
049	-96.3	133.3	479.3	3.9	051	-113.3	163.9	534.1	3.9	3.9
052	1.8	2.5	414.0	12.9	053	49.9	22.7	453.2	3.9	3.9
052	1.8	2.5	414.0	12.9	062	1.9	3.2	448.0	12.4	12.4
053	49.9	22.7	453.2	3.9	054	126.8	-19.9	496.1	1.9	1.9
053	49.9	22.7	453.2	3.9	057	107.7	40.5	477.5	3.9	3.9
054	126.8	-19.9	496.1	1.9	055	163.5	-110.7	498.1	1.9	1.9

(Sheet 1 of 3)

Table 9 (Continued)

054	126.8	-19.9	496.1	1.9	056	218.0	-53.0	509.7	1.9	1.9
057	107.7	40.5	477.5	3.9	058	162.0	153.8	513.2	1.9	1.9
057	107.7	40.5	477.5	3.9	059	157.7	55.6	516.7	3.9	3.9
059	157.7	55.6	516.7	3.9	060	210.7	37.6	550.3	1.9	1.9
059	157.7	55.6	516.7	3.9	061	215.6	73.4	541.1	3.9	3.9
062	1.9	3.2	448.0	12.4	063	1.1	-47.9	488.9	3.8	3.8
062	1.9	3.2	448.0	12.4	072	2.0	4.6	481.9	11.9	11.9
063	1.1	-47.9	488.9	3.8	064	-69.2	-101.0	532.5	1.9	1.9
063	1.1	-47.9	488.9	3.8	067	-11.2	-108.9	509.6	3.8	3.8
064	-69.2	-101.0	532.5	1.9	065	-167.4	-99.3	532.9	1.9	1.9
064	-69.2	-101.0	532.5	1.9	066	-135.7	-171.8	547.3	1.9	1.9
067	-11.2	-108.9	509.6	3.8	068	62.3	-211.9	543.7	1.9	1.9
067	-11.2	-108.9	509.6	3.8	069	-22.7	-159.0	550.2	3.8	3.8
069	-22.7	-159.0	550.2	3.8	070	-64.8	-196.4	583.7	1.9	1.9
069	-22.7	-159.0	550.2	3.8	071	-31.8	-192.2	606.0	3.8	3.8
072	2.0	4.6	481.9	11.9	073	-45.8	27.5	520.9	3.8	3.8
072	2.0	4.6	481.9	11.9	082	2.7	5.7	515.9	11.3	11.3
073	-45.8	27.5	520.9	3.8	074	-68.1	115.6	559.5	1.9	1.9
073	-45.8	27.5	520.9	3.8	077	-98.8	58.5	544.5	3.8	3.8
074	-68.1	115.6	559.5	1.9	075	-28.0	205.6	555.7	1.9	1.9
074	-68.1	115.6	559.5	1.9	076	-107.8	205.5	568.6	1.9	1.9
077	-98.8	58.5	544.5	3.8	078	-218.4	20.8	584.4	1.9	1.9
077	-98.8	58.5	544.5	3.8	079	-144.2	86.4	583.1	3.8	3.8
079	-144.2	86.4	583.1	3.8	080	-167.7	139.3	614.3	1.9	1.9
079	-144.2	86.4	583.1	3.8	081	-197.2	117.3	606.7	3.8	3.8
082	2.7	5.7	515.9	11.3	083	42.2	43.1	553.5	3.7	3.7
082	2.7	5.7	515.9	11.3	092	3.4	6.9	549.9	10.8	10.8
083	42.2	43.1	553.5	3.7	084	36.2	133.9	592.5	1.9	1.9
083	42.2	43.1	553.5	3.7	087	83.4	89.7	575.5	3.7	3.7
084	36.2	133.9	592.5	1.9	085	95.4	189.9	648.9	1.9	1.9
084	36.2	133.9	592.5	1.9	086	45.0	232.2	601.4	1.9	1.9
087	83.4	89.7	575.5	3.7	088	210.7	92.9	610.5	1.9	1.9
087	83.4	89.7	575.5	3.7	089	118.9	131.0	613.0	3.7	3.7
089	118.9	131.0	613.0	3.7	090	125.2	188.9	644.0	1.9	1.9
089	118.9	131.0	613.0	3.7	091	160.1	177.6	635.0	3.7	3.7
092	3.4	6.9	549.9	10.8	093	22.4	-41.8	590.6	3.7	3.7
092	3.4	6.9	549.9	10.8	102	3.9	8.6	583.8	10.2	10.2
093	22.4	-41.8	590.6	3.7	094	108.6	-69.5	631.7	1.8	1.8
093	22.4	-41.8	590.6	3.7	097	49.3	-96.8	616.2	3.7	3.7
094	108.6	-69.5	631.7	1.8	095	137.1	-142.6	692.8	1.8	1.8
094	108.6	-69.5	631.7	1.8	096	196.0	-115.5	643.5	1.8	1.8
097	49.3	-96.8	616.2	3.7	098	2.3	-213.4	658.3	1.8	1.8
097	49.3	-96.8	616.2	3.7	099	73.5	-143.4	656.7	3.7	3.7
099	73.5	-143.4	656.7	3.7	100	124.5	-170.0	689.6	1.8	1.8
099	73.5	-143.4	656.7	3.7	101	100.4	-198.3	682.2	3.7	3.7
102	3.9	8.6	583.8	10.2	103	-32.9	49.1	621.8	3.6	3.6
102	3.9	8.6	583.8	10.2	112	3.9	10.7	617.8	9.7	9.7
103	-32.9	49.1	621.8	3.6	104	-122.6	43.1	665.1	1.8	1.8
103	-32.9	49.1	621.8	3.6	107	-65.7	69.9	675.8	3.6	3.6
104	-122.6	43.1	665.1	1.8	105	-177.7	103.9	722.0	1.8	1.8
104	-122.6	43.1	665.1	1.8	106	-221.3	50.6	677.9	1.8	1.8
107	-65.7	69.9	675.8	3.6	108	-51.6	170.9	761.3	1.8	1.8
107	-65.7	69.9	675.8	3.6	109	-109.9	102.5	713.4	3.6	3.6
109	-109.9	102.5	713.4	3.6	110	-169.5	105.4	742.7	1.8	1.8
109	-109.9	102.5	713.4	3.6	111	-160.1	142.9	730.1	3.6	3.6
112	3.9	10.7	617.8	9.7	113	54.4	32.5	655.7	3.6	3.6
112	3.9	10.7	617.8	9.7	122	4.5	13.0	651.7	9.2	9.2
113	54.4	32.5	655.7	3.6	114	133.4	-10.4	699.9	1.8	1.8
113	54.4	32.5	655.7	3.6	117	117.7	45.4	672.9	3.6	3.6
114	133.4	-10.4	699.9	1.8	115	169.4	-103.8	705.7	1.8	1.8

(Sheet 2 of 3)

Table 9 (Concluded)

114	133.4	-10.4	699.9	1.8	116	226.4	-45.3	713.4	1.8	1.8
117	117.7	45.4	672.9	3.6	118	188.4	156.4	696.1	1.8	1.8
117	117.7	45.4	672.9	3.6	119	171.2	56.7	711.2	3.6	3.6
119	171.2	56.7	711.2	3.6	120	224.2	33.8	744.8	1.8	1.8
119	171.2	56.7	711.2	3.6	121	208.7	65.0	765.9	3.6	3.6
122	4.5	13.0	651.7	9.2	123	3.4	-38.6	694.5	3.5	3.5
122	4.5	13.0	651.7	9.2	132	5.1	14.8	685.6	8.6	8.6
123	3.4	-38.6	694.5	3.5	124	-68.9	-90.8	741.1	1.8	1.8
123	3.4	-38.6	694.5	3.5	127	-4.2	-99.0	722.5	3.5	3.5
124	-68.9	-90.8	741.1	1.8	125	-169.4	-87.2	742.7	1.8	1.8
124	-68.9	-90.8	741.1	1.8	126	-138.1	-161.7	758.4	1.8	1.8
127	-4.2	-99.0	722.5	3.5	128	79.3	-195.4	764.1	1.8	1.8
127	-4.2	-99.0	722.5	3.5	129	-11.0	-150.2	765.3	3.5	3.5
129	-11.0	-150.2	765.3	3.5	130	-50.2	-190.6	801.7	1.8	1.8
129	-11.0	-150.2	765.3	3.5	131	-18.5	-210.6	793.4	3.5	3.5
132	5.1	14.8	685.6	8.6	133	-14.7	67.5	722.4	3.5	3.5
132	5.1	14.8	685.6	8.6	142	5.7	16.5	719.6	8.1	8.1
133	-14.7	67.5	722.4	3.5	134	30.4	150.2	758.9	1.7	1.7
133	-14.7	67.5	722.4	3.5	137	-32.4	129.1	743.1	3.5	3.5
134	30.4	150.2	758.9	1.7	135	124.0	187.9	755.3	1.7	1.7
134	30.4	150.2	758.9	1.7	136	64.8	244.9	764.3	1.7	1.7
137	-32.4	129.1	743.1	3.5	138	-148.2	188.1	778.2	1.7	1.7
137	-32.4	129.1	743.1	3.5	139	-46.9	183.8	779.6	3.5	3.5
139	-46.9	183.8	779.6	3.5	140	-27.4	241.0	809.1	1.7	1.7
139	-46.9	183.8	779.6	3.5	141	-64.6	245.3	800.2	3.5	3.5
142	5.7	16.5	719.6	8.1	143	46.1	-19.9	759.8	3.4	3.4
142	5.7	16.5	719.6	8.1	152	6.3	18.2	753.5	7.6	7.6
143	46.1	-19.9	759.8	3.4	144	138.7	-6.9	798.8	1.7	1.7
143	46.1	-19.9	759.8	3.4	147	82.6	-35.0	814.6	3.4	3.4
144	138.7	-6.9	798.8	1.7	145	199.3	-61.4	859.1	1.7	1.7
144	138.7	-6.9	798.8	1.7	146	239.7	-10.1	807.8	1.7	1.7
147	82.6	-35.0	814.6	3.4	148	75.8	-129.8	910.6	1.7	1.7
147	82.6	-35.0	814.6	3.4	149	130.2	-63.1	853.4	3.4	3.4
149	130.2	-63.1	853.4	3.4	150	192.1	-61.4	880.5	1.7	1.7
149	130.2	-63.1	853.4	3.4	151	183.3	-100.7	871.5	3.4	3.4
152	6.3	18.2	753.5	7.6	153	-45.2	39.2	792.3	3.4	3.4
152	6.3	18.2	753.5	7.6	161	6.9	20.0	787.5	7.0	7.0
153	-45.2	39.2	792.3	3.4	154	-124.5	-6.0	837.3	1.7	1.7
153	-45.2	39.2	792.3	3.4	156	-84.3	44.1	847.5	3.4	3.4
154	-124.5	-6.0	837.3	1.7	155	-218.2	-43.1	851.0	1.7	1.7
156	-84.3	44.1	847.5	3.4	157	-116.1	143.6	934.0	1.7	1.7
156	-84.3	44.1	847.5	3.4	158	-139.2	54.5	886.0	3.4	3.4
158	-139.2	54.5	886.0	3.4	159	-195.0	30.8	916.4	1.7	1.7
158	-139.2	54.5	886.0	3.4	160	-203.1	69.2	903.3	3.4	3.4
161	6.9	20.0	787.5	7.0	162	63.4	25.8	825.0	3.3	3.3
161	6.9	20.0	787.5	7.0	166	6.9	21.7	821.4	6.5	6.5
162	63.4	25.8	825.0	3.3	163	102.2	43.0	878.2	3.3	3.3
163	102.2	43.0	878.2	3.3	164	157.4	59.9	914.4	3.3	3.3
164	157.4	59.9	914.4	3.3	165	222.3	74.2	929.1	3.3	3.3
166	6.9	21.7	821.4	6.5	167	6.9	23.3	855.4	5.9	5.9
167	6.9	23.3	855.4	5.9	168	7.0	24.5	889.4	5.9	5.9
168	7.0	24.5	889.4	5.9	169	7.0	24.5	890.0	5.9	5.9
169	7.0	24.5	890.0	5.9	170	6.4	24.2	890.7	1.0	1.0
169	7.0	24.5	890.0	5.9	173	7.0	24.3	890.6	5.9	5.9
170	6.4	24.2	890.7	1.0	171	5.6	23.7	890.7	1.0	1.0
170	6.4	24.2	890.7	1.0	172	6.0	23.6	891.3	1.0	1.0
173	7.0	24.3	890.6	5.9	174	7.9	24.5	891.5	1.0	1.0
173	7.0	24.3	890.6	5.9	175	7.0	24.3	891.2	5.9	5.9
175	7.0	24.3	891.2	5.9	176	6.7	24.2	891.8	1.0	1.0
175	7.0	24.3	891.2	5.9	177	7.0	24.2	891.8	5.9	5.9

(Sheet 3 of 3)

Table 10
Example Tree Locations for Grayling, MI

Latitude	Longitude	Base Elevation	Model	Model Scale
44.696502	-84.636163	354.20	valley_oak2	0.769
44.696276	-84.636163	354.20	valley_oak2	0.769
44.696641	-84.636580	354.50	valley_oak2	1.461
44.696306	-84.636693	354.20	valley_oak2	1.461
44.697001	-84.635859	354.20	valley_oak1	1.818
44.695916	-84.636615	353.80	valley_oak1	0.909
44.695890	-84.636641	353.70	valley_oak1	1.212
44.696276	-84.636719	354.30	valley_oak1	0.848
44.697027	-84.636276	353.80	valley_oak1	0.757
44.697166	-84.636806	355.60	valley_oak1	2.121
44.697057	-84.636997	355.00	valley_oak1	0.757
44.697248	-84.635885	354.20	valley_oak1	0.727
44.696641	-84.636111	354.10	valley_pine	0.869
44.696250	-84.636198	354.20	valley_pine	0.652
44.695946	-84.636580	353.80	valley_pine	0.652
44.696389	-84.637057	354.60	valley_pine	1.304
44.696389	-84.637170	354.50	valley_pine	1.152
44.696168	-84.637587	354.60	valley_pine	1.021
44.696944	-84.637309	355.10	valley_pine	0.804
44.697222	-84.636415	353.70	valley_pine	1.086
44.697140	-84.636832	355.60	valley_pine	0.891
44.697166	-84.636198	354.30	valley_pine	0.978
44.695841	-84.637823	354.55	valley_oak1	2.500
44.695710	-84.638429	358.77	valley_oak1	2.500
44.695728	-84.638513	359.94	valley_oak1	2.500
44.698257	-84.647789	364.20	forest_pine	1.003
44.698341	-84.647751	363.70	forest_pine	1.007
44.698185	-84.647766	365.30	forest_pine	1.090
44.698147	-84.647896	365.10	forest_oak1	0.934
44.698307	-84.647797	363.70	forest_oak1	1.040
44.698219	-84.647728	365.10	forest_pine	0.945
44.698162	-84.647827	365.30	forest_pine	0.999
44.698868	-84.646957	363.50	forest_pine	0.925
44.698959	-84.646393	363.90	forest_oak1	0.917
44.698792	-84.646912	363.40	forest_pine	0.978
44.698551	-84.647034	365.40	forest_pine	0.955
44.699314	-84.645317	368.20	forest_oak1	0.974
44.698685	-84.647125	364.40	forest_pine	1.097

Table 11
Foliage Data

Tree Type	Average Length	Average Width	Comment
Black Oak	11 cm	6 cm	Leaf
Jack Pine	3 cm	—	Needle

Table 12
Model Parameters for Deciduous Forest Canopies

Model Parameter	Top Layer	Middle Layer	Bottom Layer
Leaf frequency distribution factor	1	1	1
Leaf clumpiness factor	0.1	0.1	0.1
Leaf area index	3.4	0.8	0.4
Longwave emissitivity	0.98	0.98	0.98
Fractional shortwave absorption coefficient	0.089	0.042	0.040
Leaf stomatic resistance to water vapor diffusion	0.07	0.07	0.07

Table 13
Model Parameters for Coniferous Forest Canopies

Model Parameter	Top Layer	Middle Layer	Bottom Layer
Leaf frequency distribution factor	1	1	1
Leaf clumpiness factor	0.1	0.1	0.1
Leaf area index	1.5	5.3	1.0
Longwave emissitivity	0.98	0.98	0.98
Fractional shortwave absorption coefficient	0.389	0.019	0.028
Leaf stomatic resistance to water vapor diffusion	0.66	0.66	0.66

Table 14
Texture Image Data for Grayling, MI

Texture File Name	Description	Time, 24 hr
CA060[1-3].syn	Deciduous Forest Canopy	0600
CA150[1-3].syn	Deciduous Forest Canopy	1500
CA190[1-3].syn	Deciduous Forest Canopy	1900
GR080[1-3].syn	Grassy Field	0800
GR120[1-3].syn	Grassy Field	1200
GR200[1-3].syn	Grassy Field	2000
GS100[1-3].syn	Grass/Shrub Field	1000
GS150[1-3].syn	Grass/Shrub Field	1500
GS190[1-3].syn	Grass/Shrub Field	1900
SO100[1-3].syn	Bare Soil	1000
SO150[1-3].syn	Bare Soil	1500
SO190[1-3].syn	Bare Soil	1900
TR080[1-3].syn	Single Deciduous Tree	0800
TR140[1-3].syn	Single Deciduous Tree	1400
TR200[1-3].syn	Single Deciduous Tree	2000

Table 15
Standard Deviation of Apparent Temperature of Selected Terrain Cover Types at Grayling, MI, Imaged in Two Thermal Wave Bands

Time mm/dd/yy hh:mm:ss	Terrain Cover Types							
	Grassy Field		Single Deciduous Tree		Coniferous Treeline		Dirt Road	
	3-5 μm	8-12 μm	3-5 μm	8-12 μm	3-5 μm	8-12 μm	3-5 μm	8-12 μm
09/19/92 01:20:07	0.3	0.3	0.1	0.2	0.3	0.4	0.2	0.8
09/19/92 14:00:07	0.5	0.5	0.4	0.7	0.6	0.8	0.8	0.7
09/19/92 18:00:05	0.3	0.3	0.3	0.3	0.2	0.4	0.4	0.4
09/20/92 11:00:05	0.4	0.4	0.4	0.4	0.6	0.5	1.4	1.0
09/20/92 15:30:09	0.8	0.8	0.6	0.6	0.9	0.9	1.4	0.8
09/23/92 08:20:04	0.4	0.3	0.5	0.4	0.5	0.5	0.8	0.3
09/23/92 15:00:04	1.3	1.0	1.2	1.5	1.7	1.4	1.7	1.4

Elevation

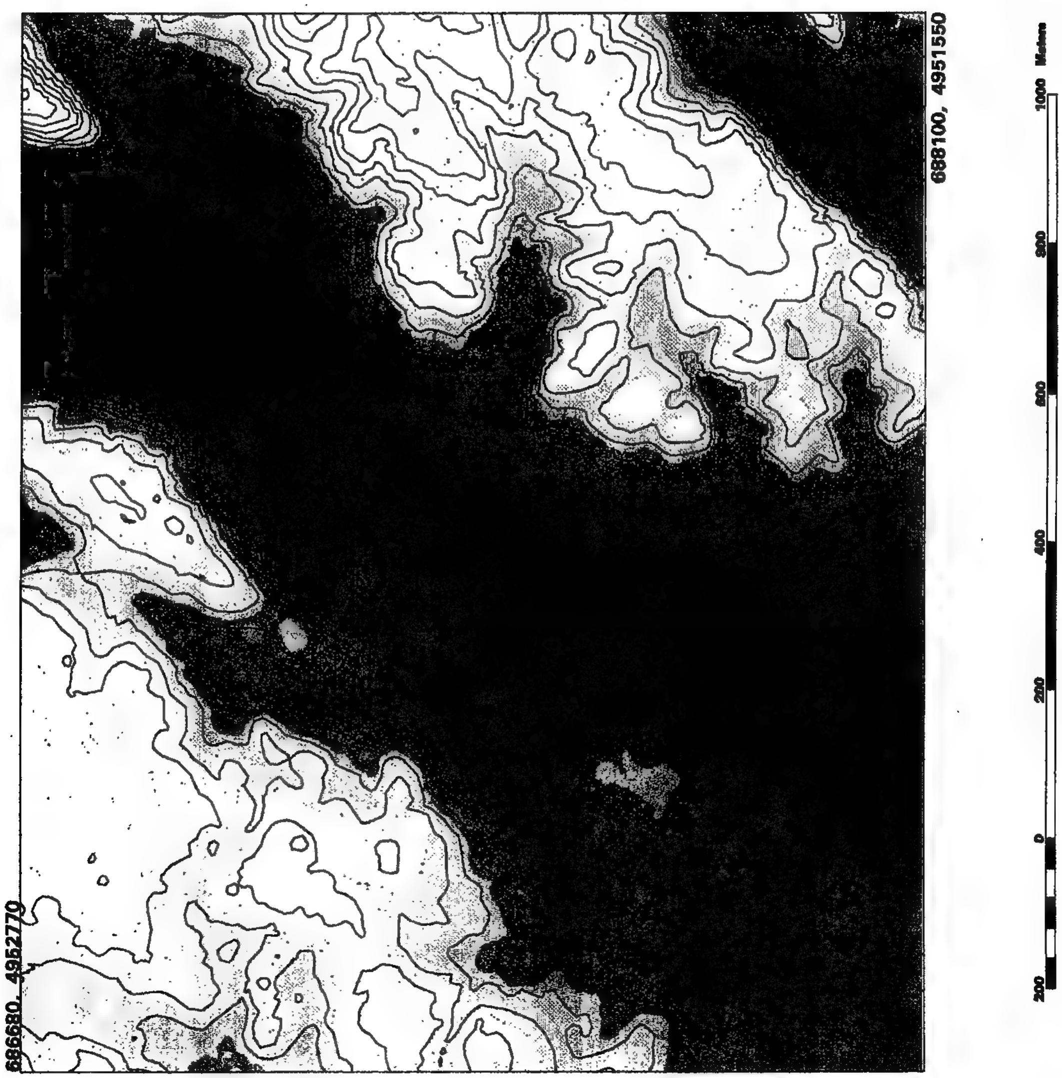


Plate 1

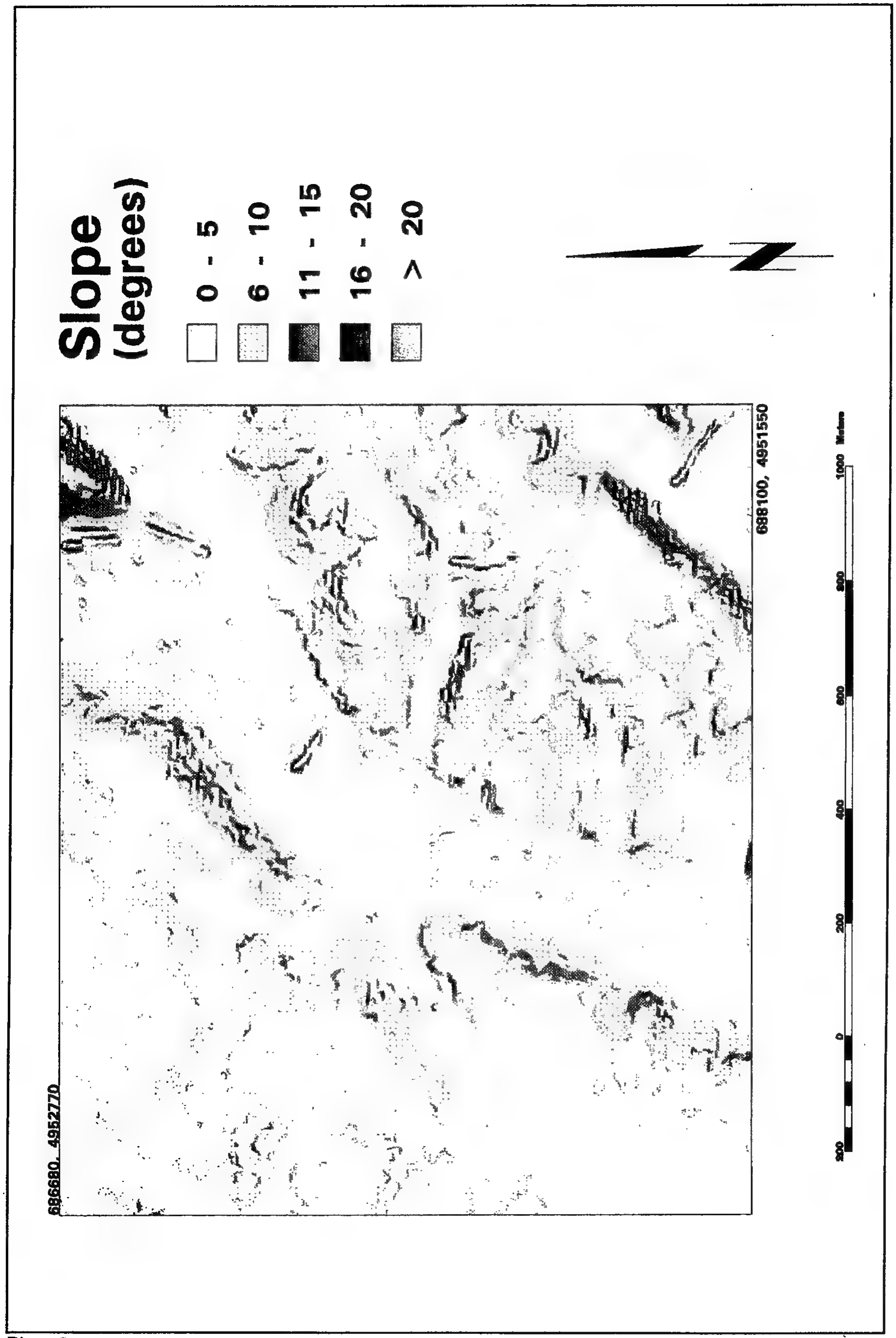

Slope
(degrees)
0 - 5
6 - 10
11 - 15
16 - 20
> 20
686680, 4952770
688100, 4951550
Meters

Plate 2

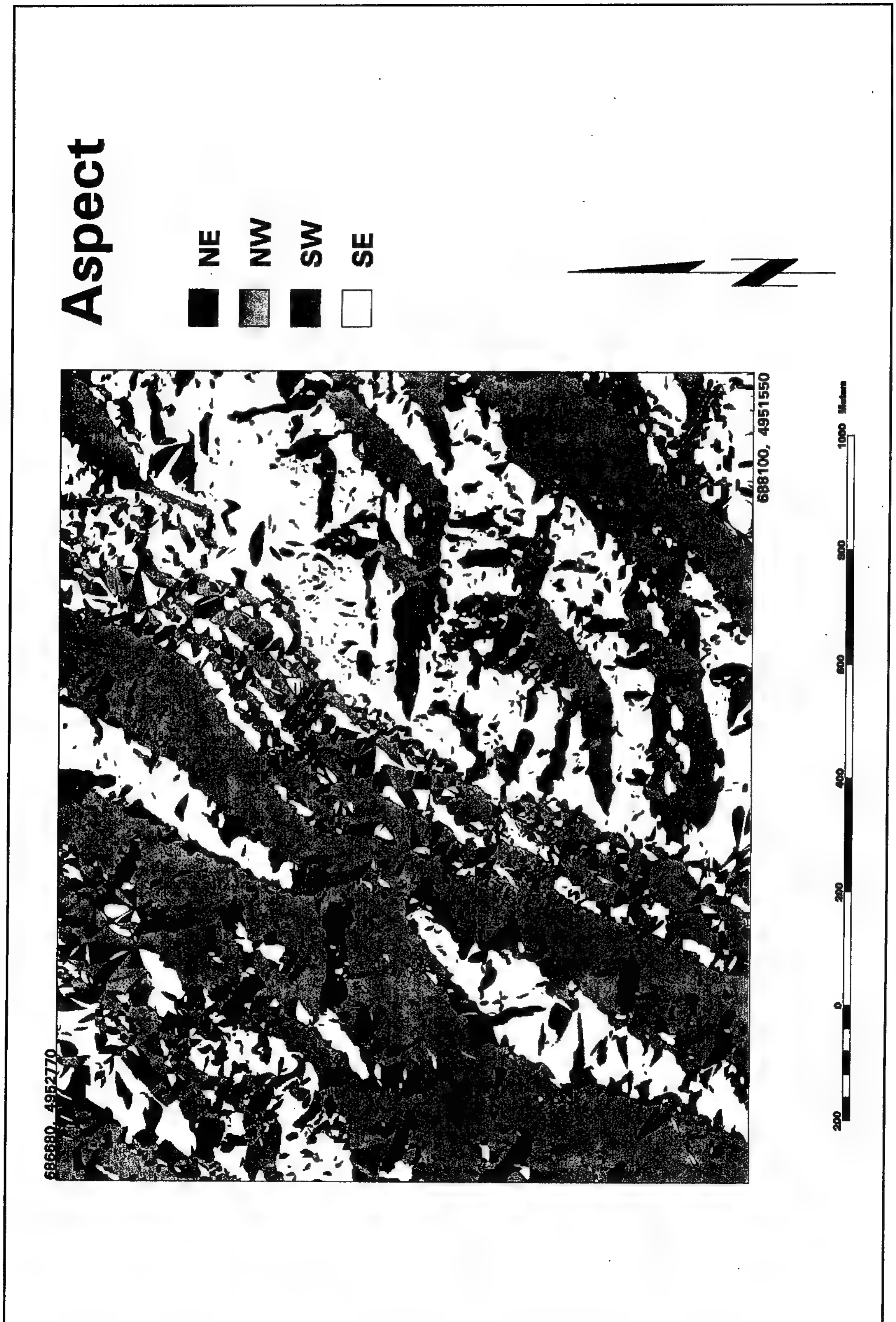
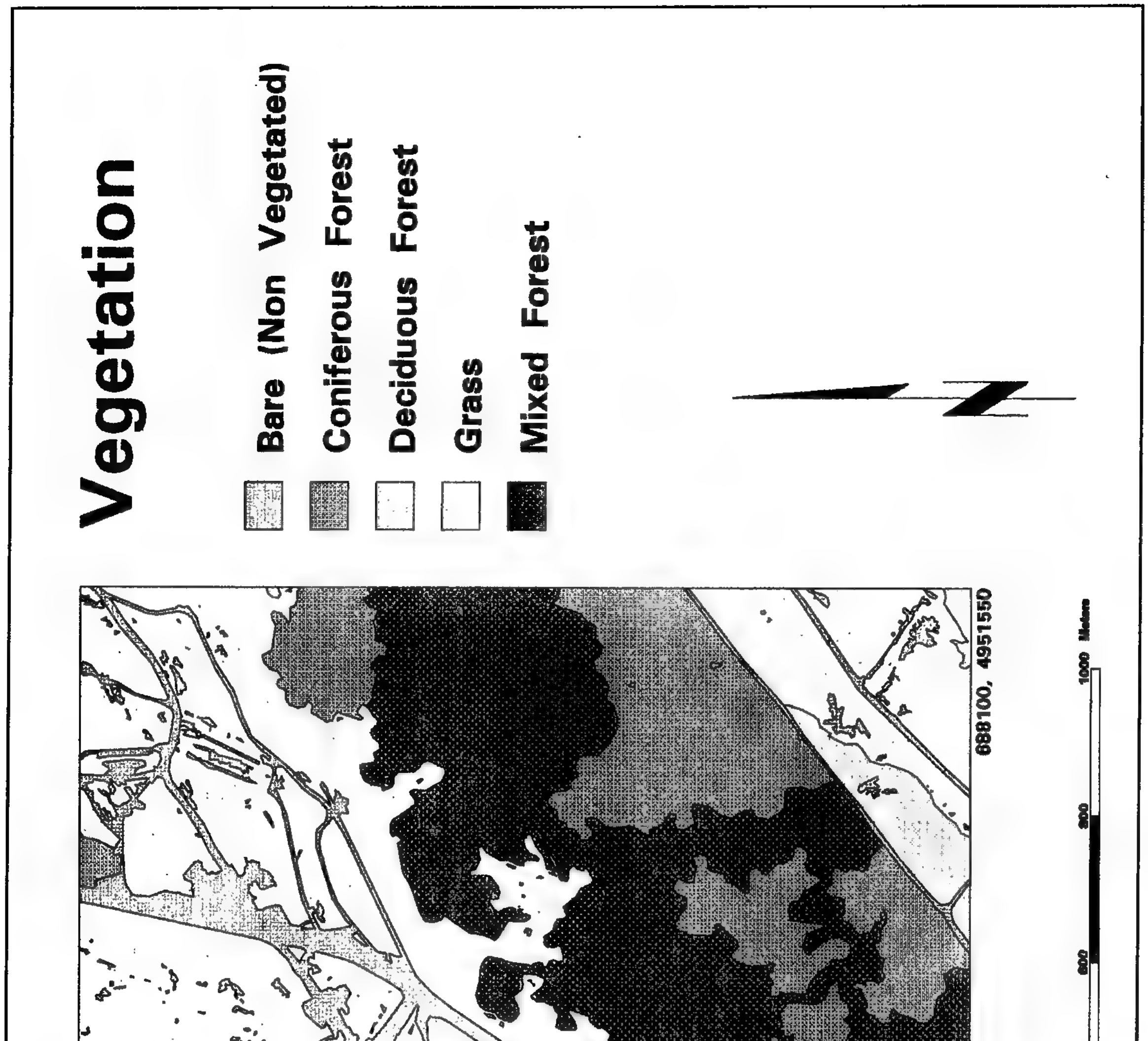

Aspect
NE
NW
SW
SE
686680, 4952770
688100, 4951550
200
0
200
400
600
800
1000

Plate 3


Vegetation
Bare (Non Vegetated)
Coniferous Forest
Deciduous Forest
Grass
Mixed Forest
686680, 4952770
688100, 4951550
200
0
200
400
600
800
1000 Meters
Plate 4

Landscape Features

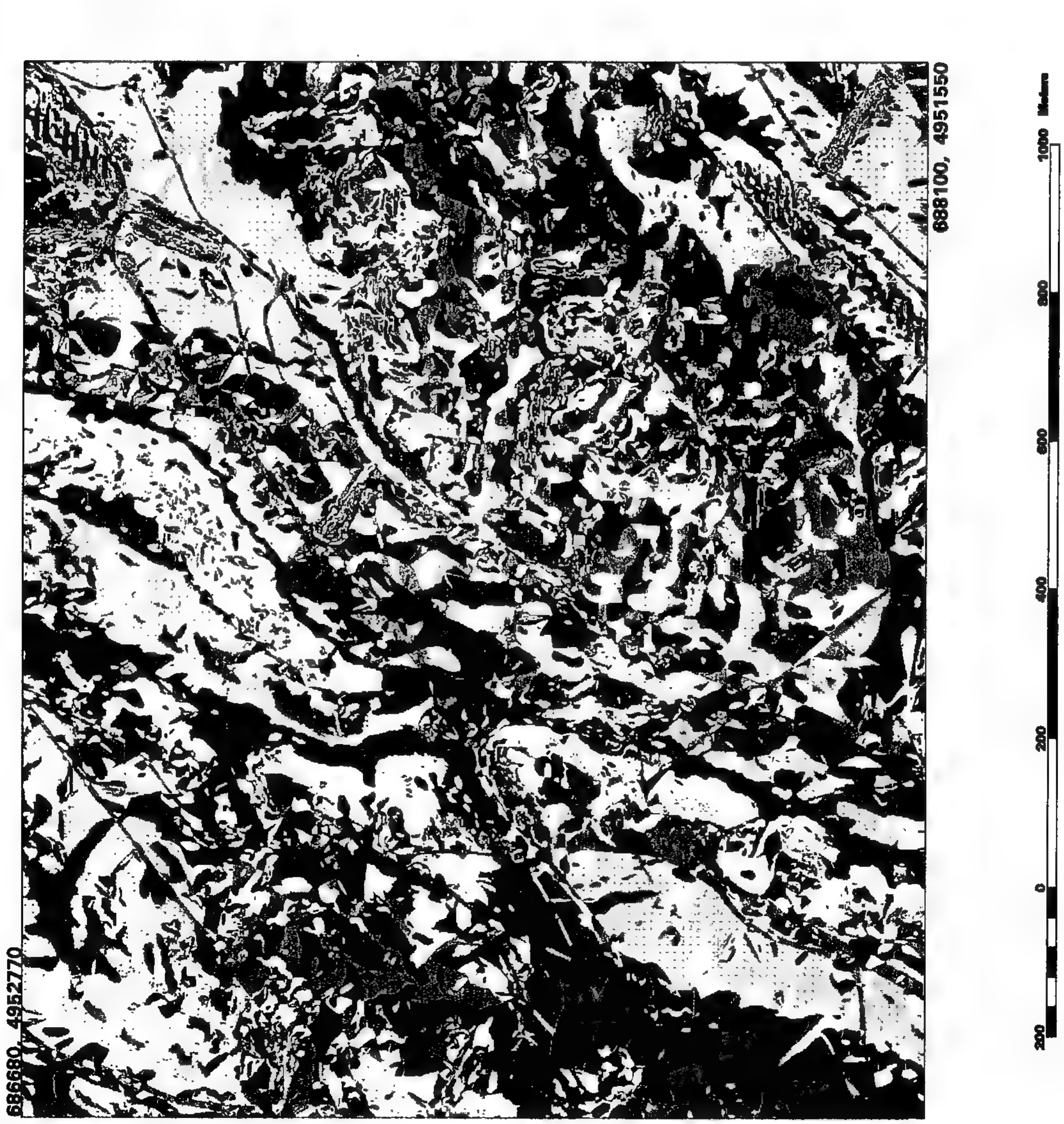


Plate 5

Plate 6

Plate 7

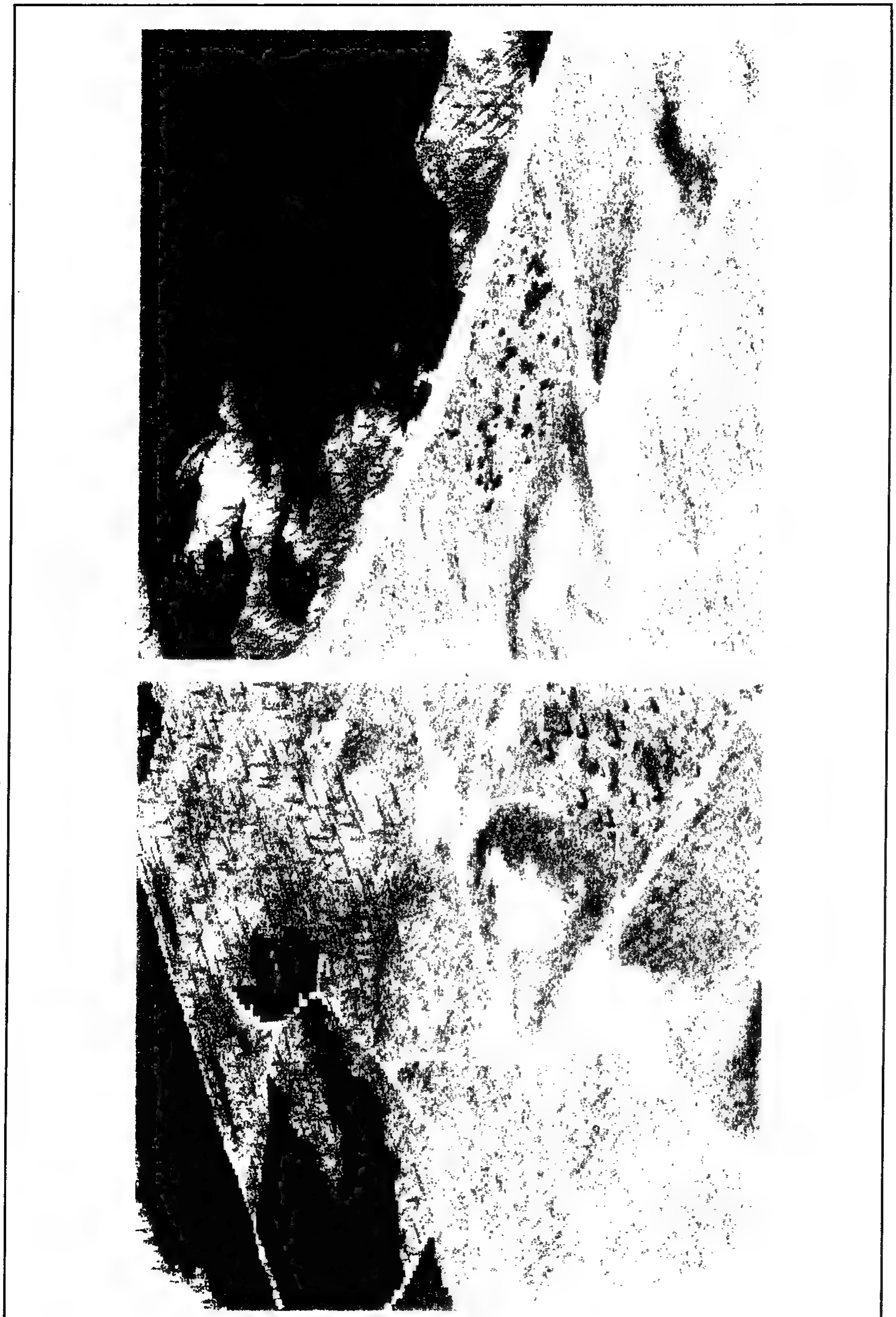


Plate 8

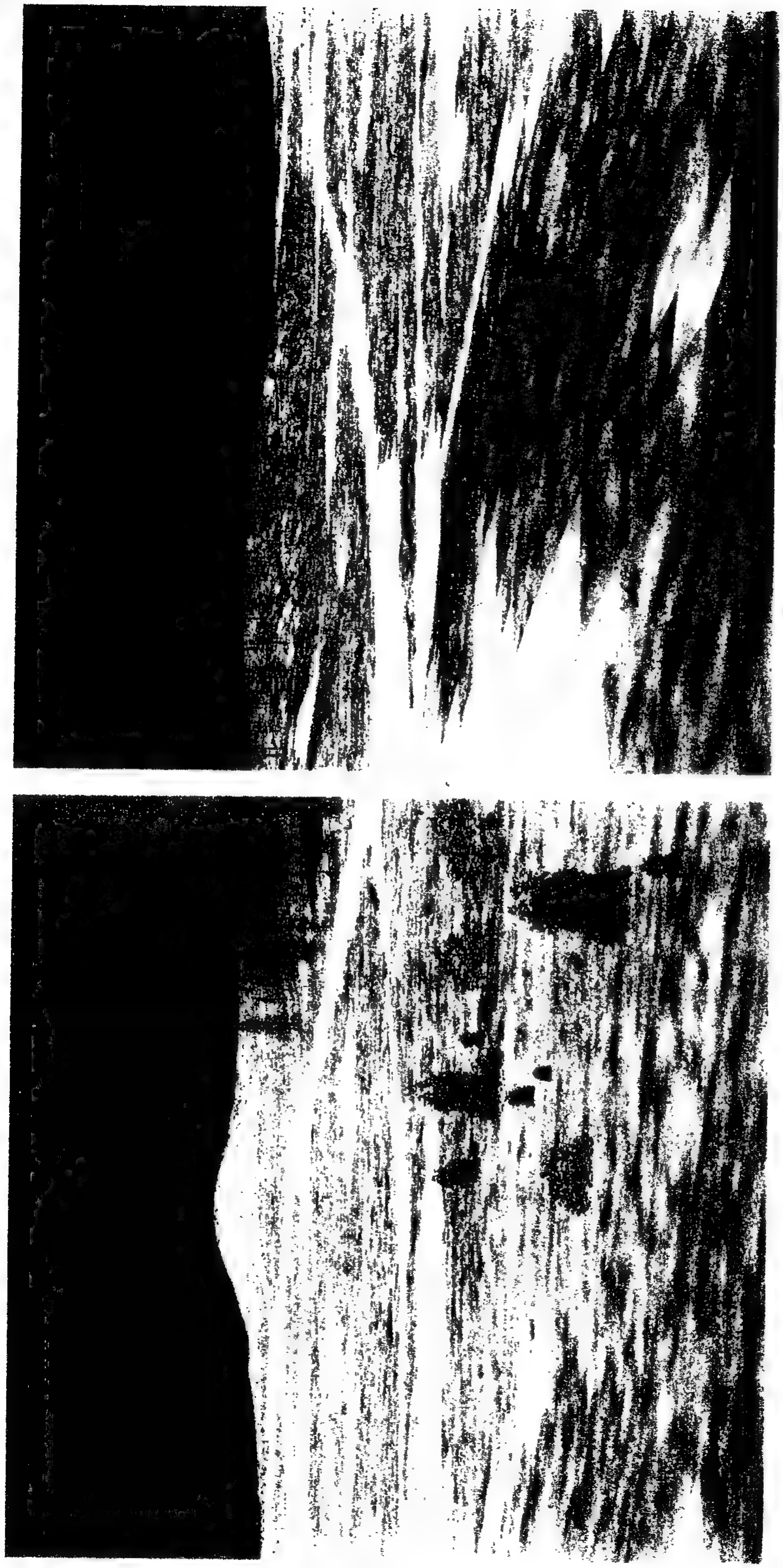


Plate 9

Appendix A
Information Base File Formats

Meteorological Data

The Grayling 1 Information Base contains two different files describing the meteorological conditions during the program: standard meteorological data and solar flux data. A text description of the standard meteorological data (*.met files) is as follows:

line 1: General Information

line 2: Altitude of Station (meters above MSL), Latitude Longitude, Time Flag

line 3: Time Step, Number of Steps, Year, Season Flag, Dry Soils Flag

line 4,5: Day, Time, Pressure, Temperature, Relative Humidity, Wind Speed, Wind Direction, Visibility, Aerosol Flag, Precipitation Amount, Precipitation Type, Low Cloud Amount, Low Cloud Type, Medium Cloud Amount, Medium Cloud Type, High Cloud Amount, High Cloud Type, Global Solar, Direct Solar, Diffuse Solar, IR Downwelling, Solar Zenith, Solar Azimuth

lines 6-n: Data Values

The following FORTRAN format statement describes the data values format:

```
FORMAT (2I3,I2,F7.1,3F6.1,F7.1,F5.1,I4,F7.2,I3,1X,3[F4.1,I2],4[7.1],F6.1,F7.1)
```

A text description of the solar flux data (*.sol files) is as follows:

line 1-24: Julian Day, Hour, Minute, Low Cloud Amount, Weighted Total Solar, Weighted Direct Solar, Weighted Diffuse Solar, Clear Sky Total Solar, Clear Sky Direct Solar, Clear Sky Diffuse Solar, Overcast Total Solar, Overcast Direct Solar, Overcast Diffuse Solar

The following FORTRAN format statement describes the data values format:

```
FORMAT (I3,I2,I2,F3.1,9[F6.1])
```

In Jeff Koening's report "Grayling 1 Data Review and Archive Databases," these data values and procedures are described in detail.

Texture Data

Each texture image file contains 256 by 256 pixels of 8-bit binary gray level data with a 512-byte header. These conform to the CIG format specifications. Gray levels are normally distributed with a mean of 128 and a standard deviation of 32. Resolution cell size of the source imagery from which textures were generated is approximately 6.6 cm; therefore, each 256 by 256 texture image corresponds to a square area approximately 17 m on a side.

Appendix B
Physical Properties

Coniferous Forest Canopy

Average Needle optical properties		
	Reflectance	0.250
	Transmittance	0.224
Average soil reflectance:		0.143
Global irradiance fraction:		1.0
Diffuse irradiance fraction:		0.18
Stomatal resistance:		0.22 min/cm

Number of layers:		3
Layer 1 (top)		
	Leaf angle distribution:	Spherical
	Leaf Area Index:	0.80
	Canopy density parameter:	0.10
Layer 2		
	Leaf angle distribution:	Spherical
	Leaf Area Index:	1.0
	Canopy density parameter:	0.10
Layer 3		
	Leaf angle distribution:	Spherical
	Leaf Area Index:	0.20
	Canopy density parameter:	0.10

Computed shortwave absorption coefficients:		
	Layer 1:	0.228
	Layer 2:	0.214
	Layer 3:	0.079
	Soil:	0.306

Longwave emissivity/absorption coefficients:		
	Layer 1:	0.98
	Layer 2:	0.98
	Layer 3:	0.98
	Soil:	xxx

Deciduous Forest Canopy:

Average Leaf optical properties	
Reflectance	0.250
Transmittance	0.224
Average soil reflectance:	0.143
Global irradiance fraction:	1.0
Diffuse irradiance fraction:	0.18
Stomatal resistance:	0.07 min/cm

Number of layers:	3
Layer 1 (top)	
Leaf angle distribution:	Spherical
Leaf Area Index:	0.80
Canopy density parameter:	0.10
Layer 2	
Leaf angle distribution:	Spherical
Leaf Area Index:	0.15
Canopy density parameter:	0.10
Layer 3	
Leaf angle distribution:	Spherical
Leaf Area Index:	0.05
Canopy density parameter:	0.10

Computed shortwave absorption coefficients:

Layer 1:	0.255
Layer 2:	0.046
Layer 3:	0.038
Soil:	0.486

Longwave emissivity/absorption coefficients:

Layer 1:	0.98
Layer 2:	0.98
Layer 3:	0.98
Soil:	xxx